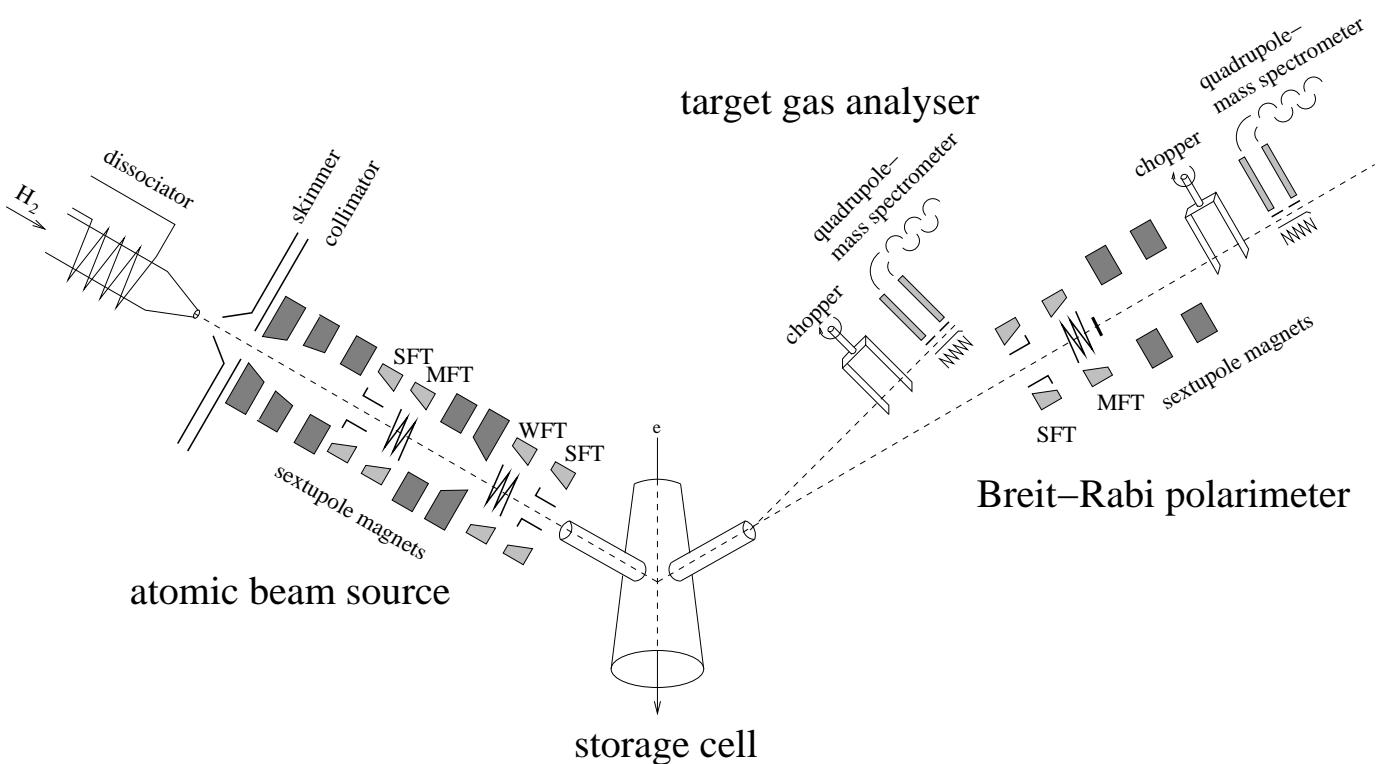




The **hermes** Polarized Atomic Beam Source

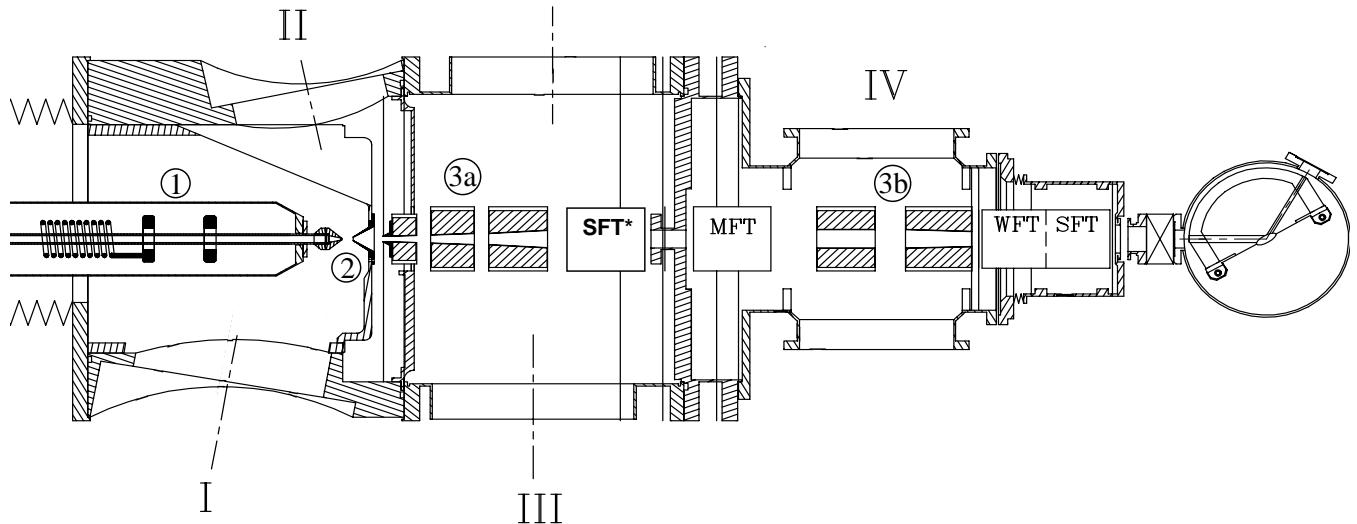
1. The HERMES target
2. Principle of operation and setup
3. Optimization procedures
4. Performance within the experiment
5. A description of the beam formation
6. Verification with a beam profile monitor
7. Discussion and outlook

The HERMES Internal Gaseous Target



- Polarized atomic beam created by the **atomic beam source (ABS)**
- Injected into the **storage cell**
- Atomic and molecular fraction measured by the **target gas analyser (TGA)**
- Polarization of the atoms measured by the **Breit–Rabi polarimeter (BRP)**

Principle of Operation and Setup of the ABS

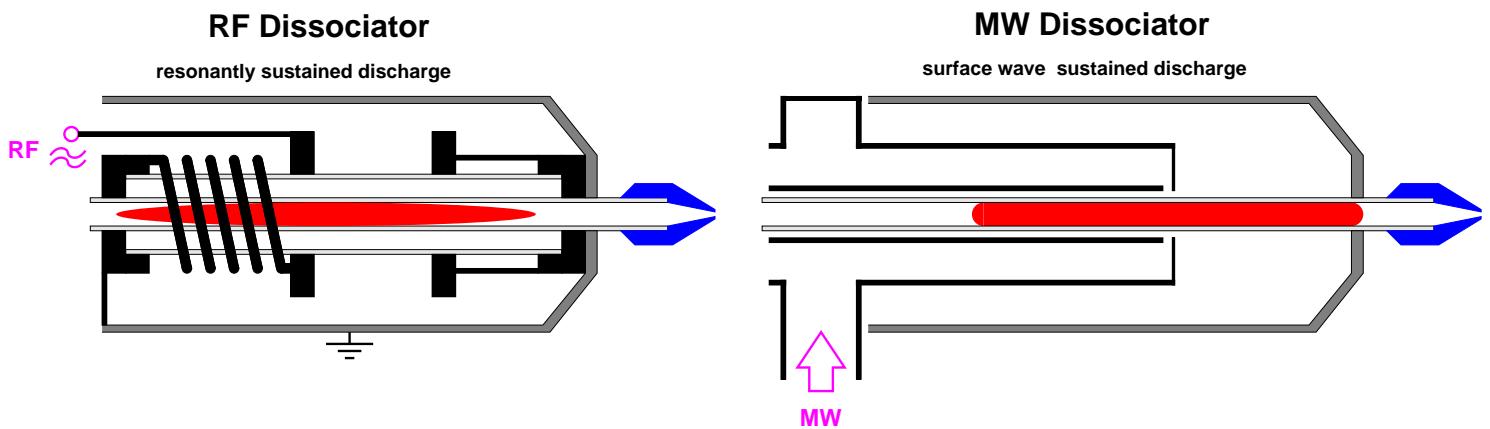


- Dissociator (1) converts molecular gas into atoms.
- Formation of a high brilliance beam using a cooled nozzle, a skimmer (2), a collimator and a powerful vacuum system (I-IV).
- Focussing of atoms with electron spin +1/2 with sextupole magnets (3) based on the Stern-Gerlach principle.
- Creation of nuclear polarization by interchange of the hyperfine state populations using high frequency transitions (SFT,MFT,WFT).
- Injection into the storage cell.

The Dissociators

Radio frequency dissociator (RFD):

- LC-circuit as a field applicator (frequency 13.56 MHz).
- Water cooled pyrex discharge tube.
- At $Q = 1 \dots 1.5 \text{ mbarl/s}$, $P_{\text{RF}} = 300 \dots 350 \text{ W}$ and $T_{\text{nozzle}} = 100 \text{ K}$ the degree of dissociation $\alpha \approx 80 \%$ (H) and 75 % (D).

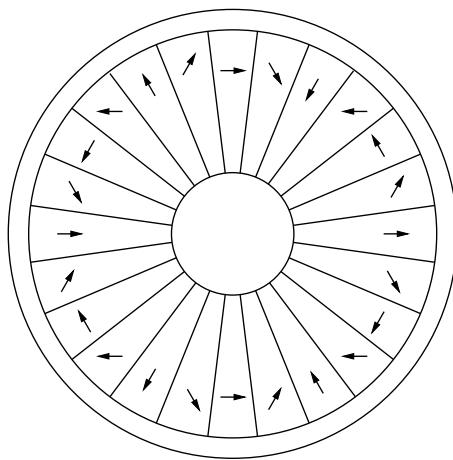


Microwave dissociator (MWD)

- Plasma source which couples a 2.45 MHz surface wave to the discharge.
- Air cooled pyrex discharge tube.
- At $Q = 1 \dots 3 \text{ mbarl/s}$, $P_{\text{MW}} = 600 \text{ W}$ and $T_{\text{nozzle}} = 100 \text{ K}$ the degree of dissociation $\alpha > 80 \%$ (H,D).
- Liquid cooling in progress.

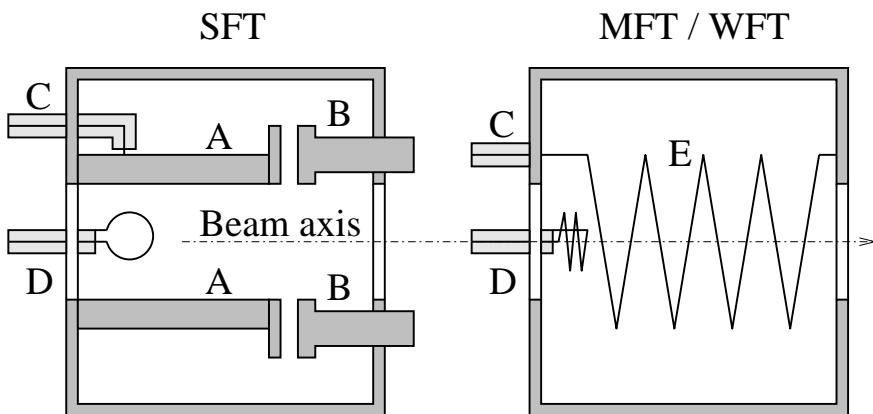
The Sextupole System

- High gradient permanent magnets.
- 24 segments made of Vacodym¹.
- Maximum poletip field is 1.5 T.
- Enclosed in vacuum tight stainless steel cans to prevent chemical destruction by hydrogen.
- First set of magnets (3a):
 - 3 magnets → low residual gas pressures inside.
 - tapered → large acceptance of the atomic beam.
- 2 more magnets (3b) focus the atomic beam into the entrance tube of the storage cell.
- Calculation of the transmission probabilities with a Monte-Carlo simulation.



¹Brand name of Vacuumschmelze GmbH, Postfach 2253, D63412 Hanau, Germany.

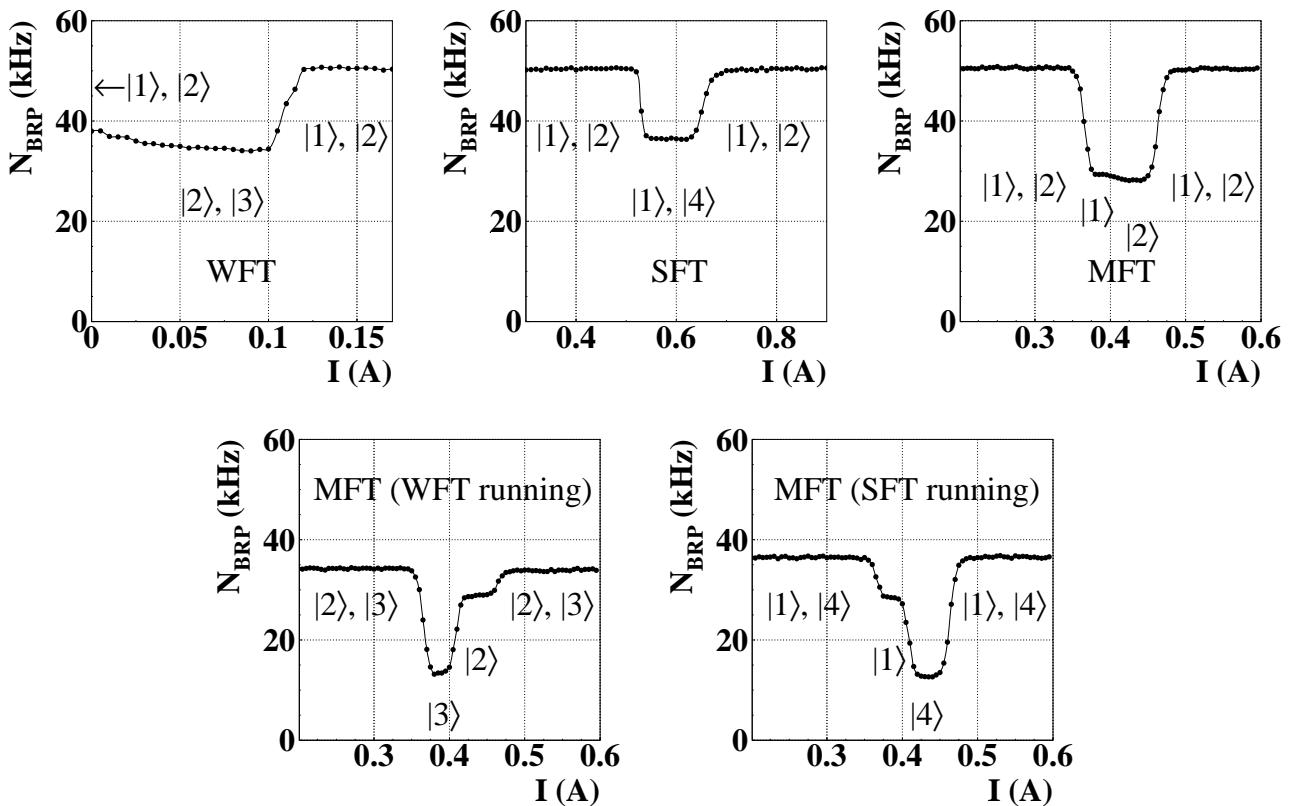
High Frequency Transitions (HFTs)



Static magnetic field

- Strong field transition SFT ($\Delta F = 1$):
 - Resonator cavity (strip line resonator) with the resonator rods (A), the capacitor plates (B), the RF-power input (C) and the pick-up loop (D).
 - Frequencies 1430 MHz (H) and 370 MHz (D).
- Medium / Weak field transition MFT/WFT ($\Delta F = 0$):
 - High frequency coil (E).
 - Frequencies:
 - * MFT: 90 MHz (H) and 25 MHz (D).
 - * WFT: 14 MHz (H) and 7 MHz (D).
- Static magnetic field with a gradient along the atomic path.

High Frequency Transitions (HFTs)

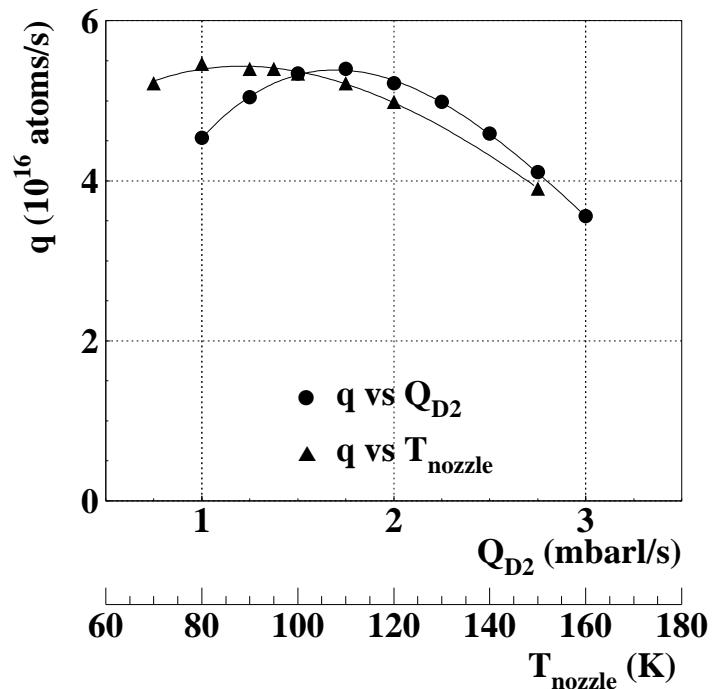


BRP-QMS signal as a function of the magnetic field $B \propto I$. The injected states of hydrogen into the target cell are shown.

- BRP transitions off → only states $|1\rangle$ and $|2\rangle$ (electron spin +1/2) reach the QMS.
- MFT can be operated exchanging the states $|2\rangle$ and $|3\rangle$ or $|1\rangle$ and $|3\rangle$ at different magnetic fields.
- Efficiencies could be obtained by spin relaxation measurements using the BRP.

→ Injection of 0, 1, 2 states using various combinations of HFT's.

Optimization Procedures

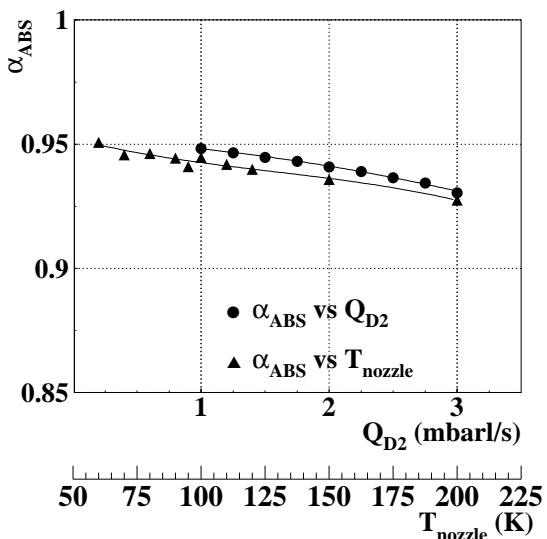


Intensity q as a function of the flux Q_{D_2} (at $T_{\text{nozzle}} = 100$ K) and the nozzle temperature T_{nozzle} (at $Q_{D_2} = 1.5$ mbar · l/s) for deuterium using the MWD.

- Intensity optimization using a calibrated compression tube.
- Maximum values:

	gas	Q (mbarl/s)	P (W)	T_{nozzle} (K)	q (atoms/s)
RFD	H	1.5	290	115	$6.5 \cdot 10^{16}$
	D	1	200	115	$5.2 \cdot 10^{16}$
MWD	H	1.5	600	80	$6.2 \cdot 10^{16}$
	D	1.5	600	80	$6.0 \cdot 10^{16}$

Optimization Procedures



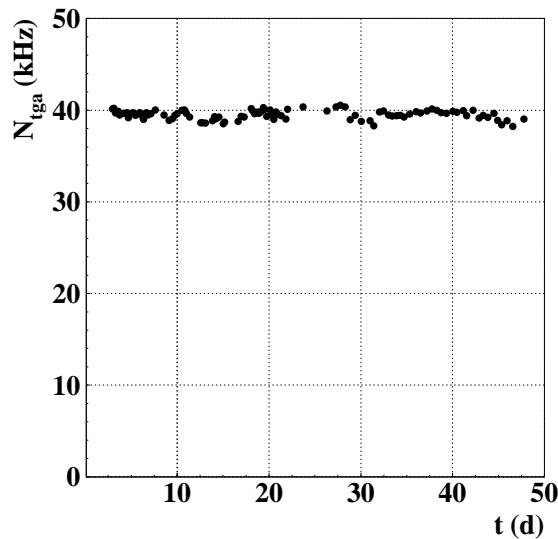
- The degree of dissociation α_{ABS} (same conditions) measured with a QMS in front of the entrance of the compression tube:

$$\alpha_{ABS} = \frac{S_a^*}{S_a^* + 2 \kappa_{ion} \kappa_{det} \kappa_v S_m},$$

- $S_a^* = (S_a - \delta^{di} S_m)$ – atomic signal corrected for dissociative ionization in the QMS,
- S_a, S_m – atomic, molecular QMS signal,
- κ_{ion} – ratio of the ionization cross sections,
- κ_{det} – ratio of the detection probabilities,
- κ_v – ratio of the velocities of the atoms and molecules.

Performance within the HERMES Experiment

Intensity

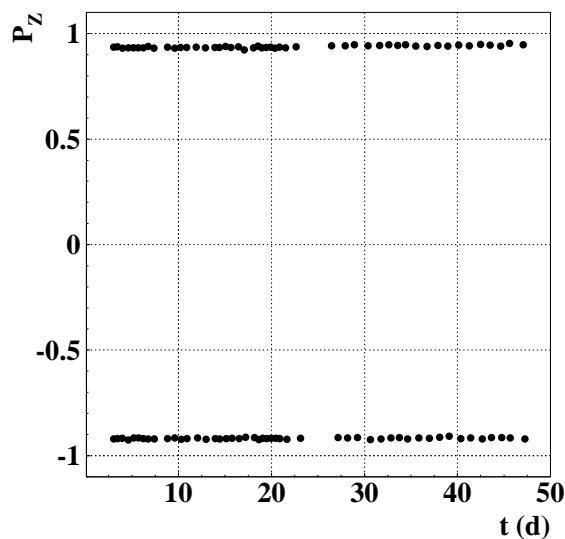


- Continuous running from 1996 until 2002.
- No direct measurement of absolute intensity.
- Relative intensity measurement with the [TGA](#).
- Intensity estimation ([BRP](#)) using spin exchange effect:

	gas	$Q \left(\frac{\text{mbarl}}{\text{s}} \right)$	$P \text{ (W)}$	$T_{\text{nozzle}} \text{ (K)}$	$q \text{ (atoms/s)}$
RFD	H	1.25	290	100	$6.6 \cdot 10^{16}$
	D	0.9	200	100	$4.5 \cdot 10^{16}$
MWD	D	1.5	600	100	$5.1 \cdot 10^{16}$

Performance within the HERMES Experiment

Polarization



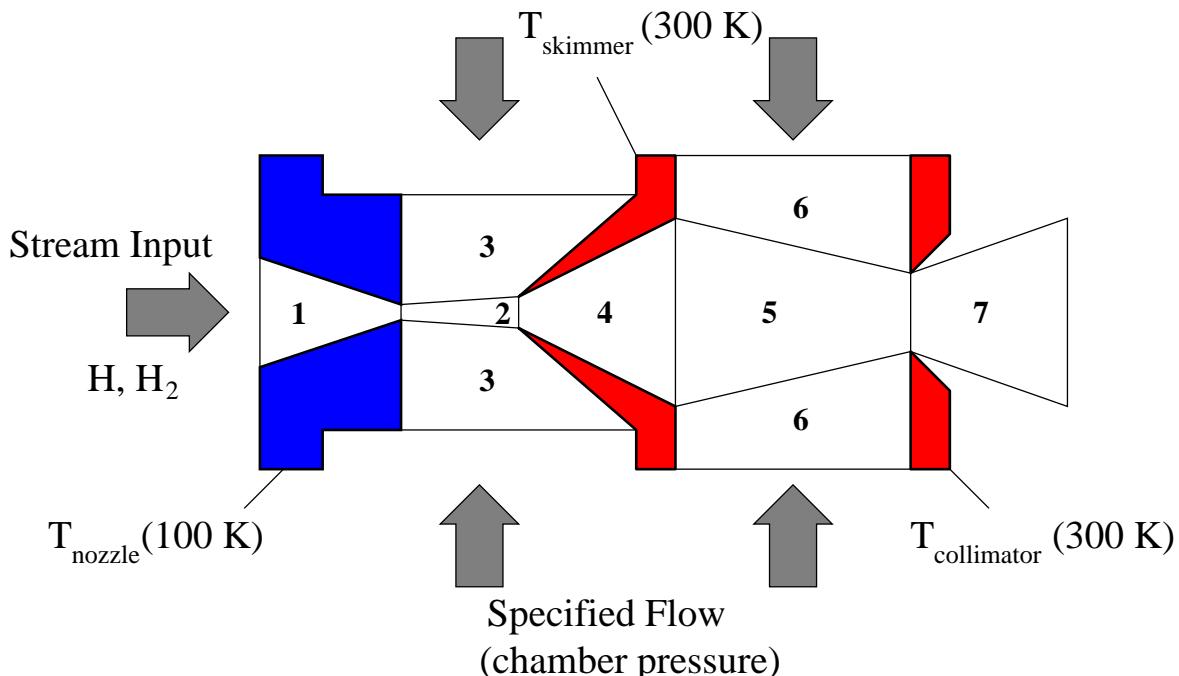
- Measurement of the target polarization with the BRP.
- Determination of the efficiencies of the HFT's.
- Transmission probabilities of the ABS-sextupole system from Monte-Carlo calculations.

→ Injected polarization from the ABS into the target cell:

gas	Inj. HFS	P_z	P_{zz}
H	$ 1\rangle 4\rangle$	$+0.973 \pm 0.010$	-
	$ 2\rangle 3\rangle$	-0.974 ± 0.010	-
D	$ 1\rangle 6\rangle$	$+0.924 \pm 0.010$	$+0.884 \pm 0.018$
	$ 3\rangle 4\rangle$	-0.911 ± 0.015	$+0.941 \pm 0.022$
	$ 3\rangle 6\rangle$	-0.015 ± 0.014	$+0.990 \pm 0.023$
	$ 2\rangle 5\rangle$	-0.022 ± 0.013	-1.774 ± 0.020

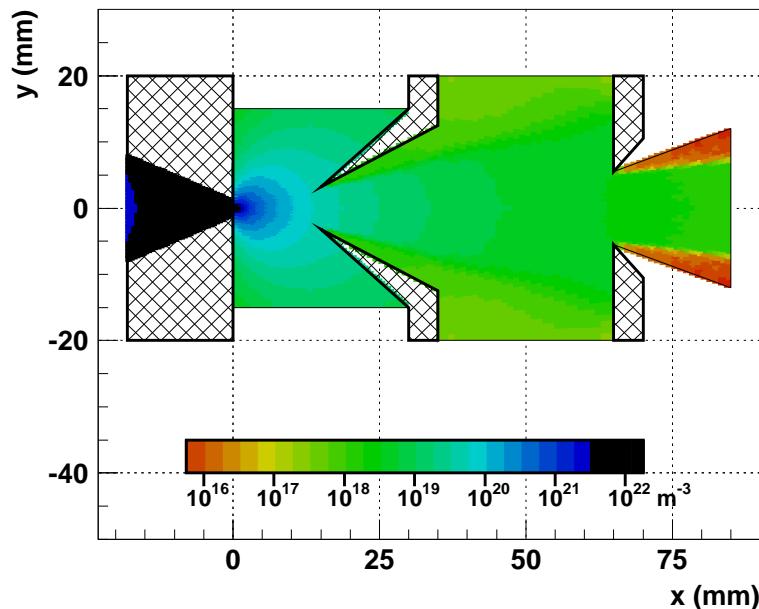
A new Description of the Beam Formation

- Transition region between laminar and molecular flow
- Direct Simulation Monte - Carlo (DSMC) method
 - Simulates binary (hard sphere) collisions between particles characterized by $d_{part}^{eff}(T)$, m_{part} , c_{coll}^{rot} (rot. collision number)
 - Input of the desired geometry (nozzle, skimmer...)
 - Space is divided into regions (1 . . . 7) and small cells
 - Generation of a sample of molecules (Stream Input)
 - Implementation of $p_{chamber}$ (Specified flow)
 - Results: n and v distribution averaged over every cell and Q inbetween the regions (nozzle throat, skimmer ...)
 - Additionally molecule output file on a desired boundary.



Monte - Carlo Simulation of an Expansion

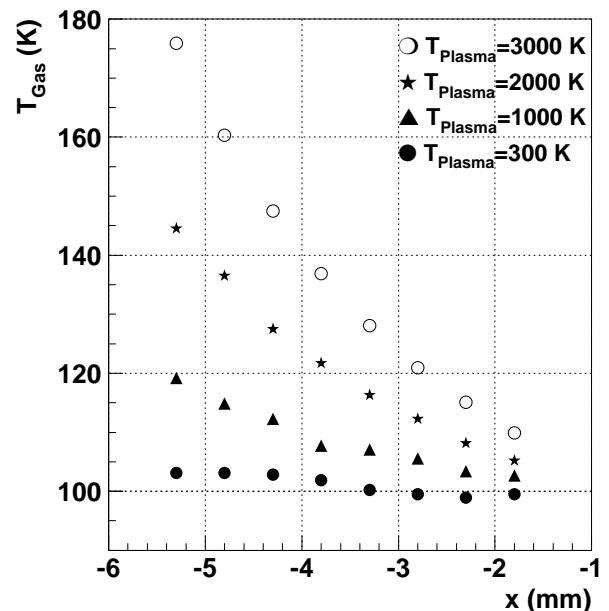
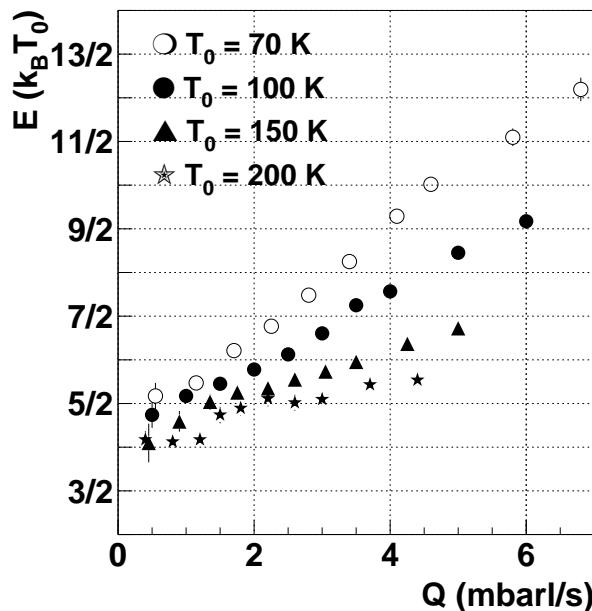
- Geometry of the ABS (dissociator and skimmer chamber)
- Stream input: 1 mbar l/s flow ($T_{\text{gas}} = 3000 \text{ K}$) of a mixture of atomic (80 %) and molecular hydrogen (20%) $\rightarrow \alpha = 67\%$
- Specified flow from p_{dissch} and p_{skimch}
- Results:



⇒ Atomic beam with small divergence after collimator.

Energy Considerations

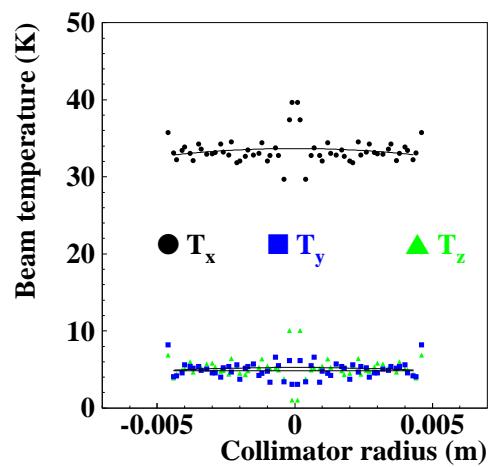
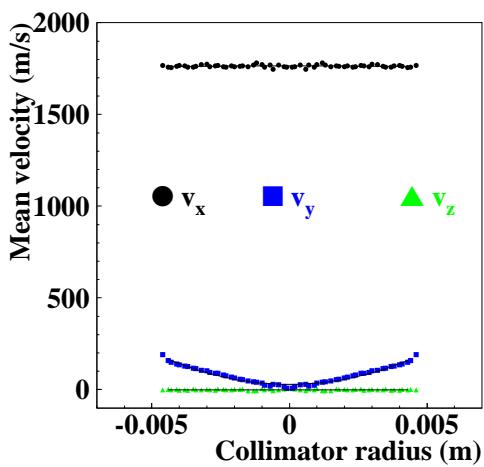
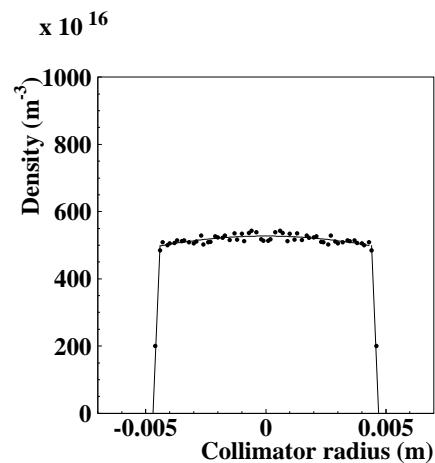
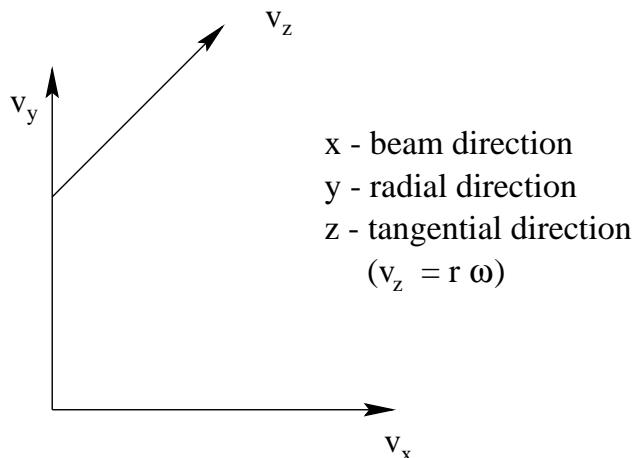
- Atomic beam parameters from TOF-measurements.
→ Beam energy (E) calculation.
- Data should be $\leq 5/2$.
→ Beam has more energy than expected.
- Reason – incomplete thermalization of the gas inside the nozzle (x – distance from nozzle exit).



- Different nozzle geometries (same exit diameter) on RFD and MWD
→ different beam parameters.

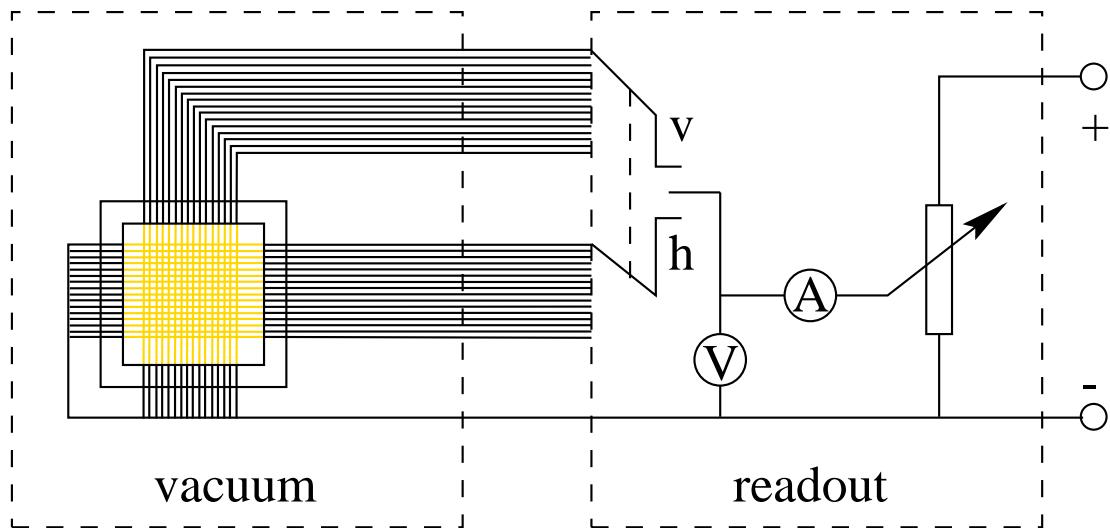
Parameters on the Collimator Surface

Density and velocity distribution at the collimator surface



⇒ Input parameters for starting generator of a Monte-Carlo simulation for a sextupole system

The Beam Profile Monitor



- Au plated W wires ($d = 5\mu m$).
- Recombination heat of the atoms on the wire \rightarrow resistance \uparrow .
- Calibration (function f) via U - I characteristics for every wire.
- $n(x, y, z)$, $v(x, y, z)$ from Monte-Carlo simulations.
- Power distribution on the wire (length l):

$$\frac{dP}{dy} = d \frac{\epsilon_r}{2} \alpha_{Au} n(y) v(y)$$

ϵ_r – recombination energy,

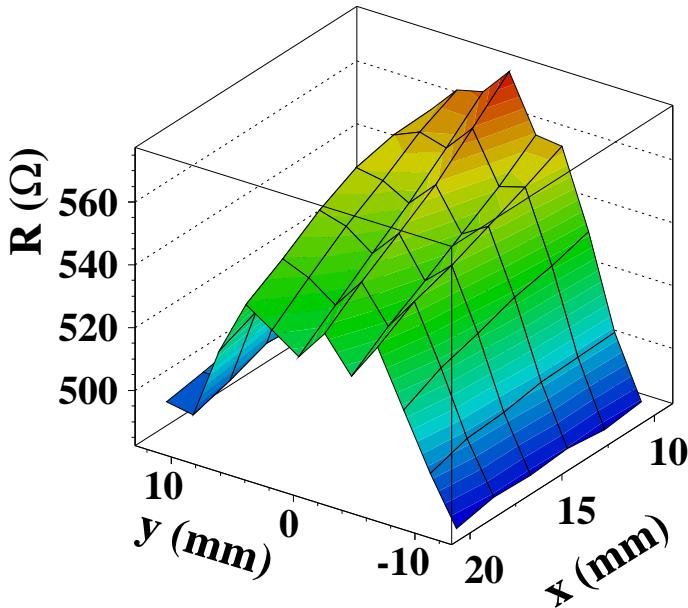
α_{Au} – accommodation coefficient of gold

$$\Rightarrow R_w = \frac{1}{l} \int_{y_a}^{y_e} f\left(\frac{dP}{dy} \cdot l\right) dy$$

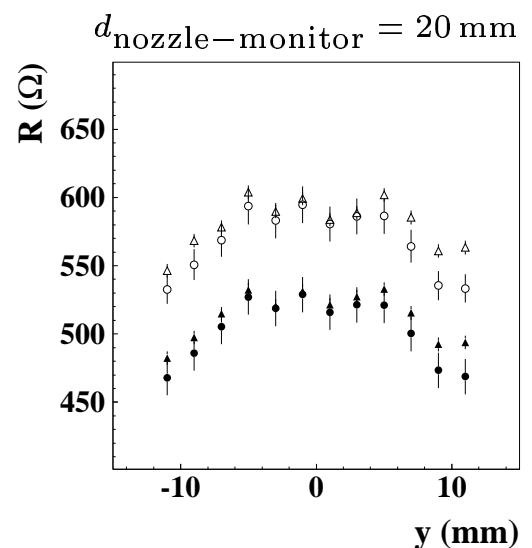
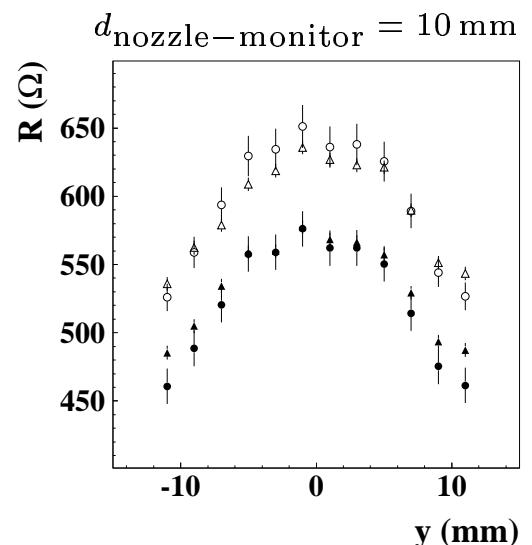
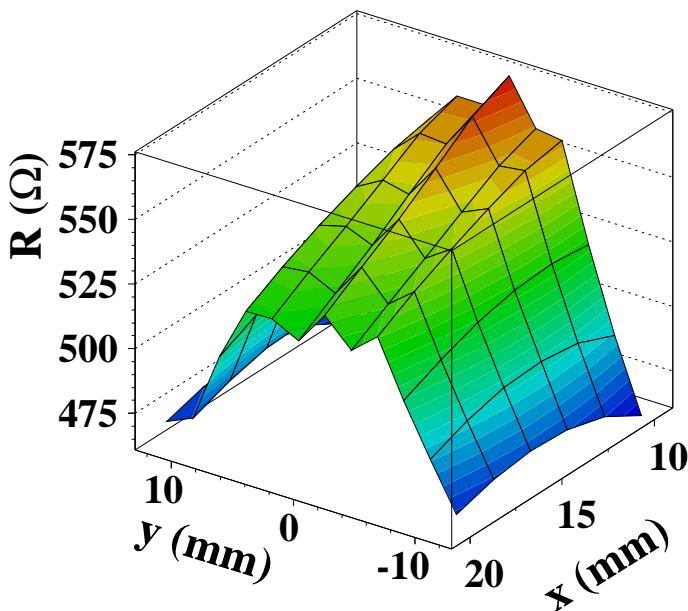
Comparision between Simulation and Measurement

Measurement of the wire resistances (R) at:

$$Q_{\text{H}_2} = 1 \text{ mbar} \cdot \text{l/s}, T_{\text{nozzle}} = 100 \text{ K}, \alpha = 80\% :$$



Calculated resistances



Q	1 mbar l/s	2 mbar l/s
simulated	●	○
measured	▲	△

Discussion

- ABS very reliable instrument to provide nuclear polarized H (D) atoms with intensities up to $6.5 \cdot 10^{16}$ atoms/s ($6.0 \cdot 10^{16}$ atoms/s) in 2 (3) hyperfine substates.
- Nuclear polarization values of 0.97 (0.92) at a degree of dissociation of 92% (95%) for H (D).
- Insertion of the new MWD → improvement of the deuterium intensity by 15%.
- Smooth and stable operation within the HERMES experiment over a long time period.
- Monte Carlo simulations excellent tool to describe the formation of atomic beams.
- Results verified by many measurements including velocity measurements and the beam profile monitor.

Outlook

- ABS providing polarized hydrogen atoms for a transverse target.
- Test and installation of a liquid cooled MWD.
- Sextupole Monte-Carlo simulations with the new starting generator
⇒ New or modified sextupole system.